Site Response of the Chi-Chi Taiwan Earthquake

Final Technical Report

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Investigations Undertaken

We have conducted research on strong motion site response and nonlinear site effect of the Chi-Chi Taiwan earthquake. A total of 590 strong motion acceleration seismograms from the Chi-Chi earthquake were analyzed. We divided the data into different groups according to their station site conditions and source-site distances. The station site condition were classified into three categories: site 1: hard sites, site 2: medium sites, site 3: soft soil sites. The source-site distance is divided into four different ranges, D<20km, 20<D<50km, 50<D<100km, and D>100km. Figures 1 shows the distribution of the stations in terms of site classification and distance.

Results

Site response based on acceleration response spectra was thoroughly examined. Our study indicated that the spectra responses from different site categories differ significantly in both amplitude and spectra shape. Figure 2 compares the averaged acceleration response spectra of different site categories for the four different distance ranges. In Figure 2a and 2b, for distances less than 50 km, the response spectral are higher for soft soil sites than for medium or hard sites at low frequencies but the trend is opposite at higher frequencies. The crossover occurred at about 1 Hz. At lower frequencies, the average soil responses are higher than that of the rock responses, apparently due to site amplification at soft soil sites. At higher frequencies, however, soil motions become lower than rock motions. This characteristic can be easily explained by nonlinear site response at soft soil sites. In Figure 2d, for distance over 100 km, the soil site response is consistently higher than rock site response over the whole frequency range observed. There is no crossover happened as in Figure 2a and 2b. At this distance range we generally do not expect nonlinearity effect. In Figure 2c for distance range of 50 to 100 km, while the soil motion is great than the rock motion at lower

frequencies, they become close to each other for frequencies above 1 Hz. This is due to the result of decreasing soil nonlinearity at high frequency at this distance range. To better visualize this soil nonlinearity and soil amplification effect relative to hard sites, in Figure 3 we have plotted the ratios of the response spectra for different groups. At high frequencies (f>1Hz), we can see the response spectra are smaller on the soft sites at distances less than 50 km, about equal for distances between 50 and 100 km, and greater for distances greater than 100 km as compared to hard sites.

About results are remarkably consistent with the result by Su et al (1998) in their Northridge nonlinear site response study. Figure 4 re-plots Figures 10-12 of Su et al (1998) but uses a conventional engineering expression, that is, we use an averaged strong to weak motion ration (ASW ratio) instead of averaged weak to strong motion ratio (AWS ratio). The significant point here is the threshold of nonlinearity recognized in the Su et al paper: peak acceleration of about 0.3 g, peak velocity of about 20 cm/s, or peak strain of about 0.06% from the Northridge earthquake. Figure 5 and 6 show the distance dependence of peak velocity, peak acceleration and SA at 1 Hz for both Chi-Chi and Northridge earthquakes. It is evident that peak accelerations have dropped under the 0.3g threshold over about 40 km for both earthquakes. On the other hand, peak velocities have dropped below the 20 cm/s threshold over 40-50 km for Northridge, but not until about 110 km in the Chi-Chi earthquake. Su et al (1998) point out that nonlinearity is theoretically most closely correlated with shear strain. Velocity should be better correlated with strain than acceleration, giving a basis for expecting that the nonlinearity should be present in distance ranges where velocity, rather than acceleration, exceeds the threshold found in the Northridge earthquake. The results from Chi-Chi earthquake are consistent with those of Northridge earthquake.

Non-technical Summary

The objective of this project is to conduct research on strong motion site response and nonlinearity effect study. We have found spectra response is strongly site condition dependent and we have established a threshold for nonlinearity. Our results are an important step forward in understanding ground motion response and it will provide important information to engineers in their designs on earthquake resistance buildings and structures.

Publications

Su, F., Y. Zeng and J. G. Anderson (2003). Influence of earthquake magnitude, propagation path, recording site amplification and nonlinearity effect on ground motion response spectra and its engineering application, submitted to BSSA.

Su, F., Y. Zeng and J. G. Anderson (2002). Ground motion response spectra from recent large earthquakes and its dependence on earthquake magnitude, propagation path and local site effect, *EOS, Trans. A.G.U.*, **83**, F1061.

Zeng, Y. and C. H. Chen (2001). A combined GPS measurements and strong motion waveform inversion of the source rupture process during the 1999 Chi Chi, Taiwan earthquake, Bull. Seis. Soc. Am. 91, 1088-1098.

References

Su, F., John G. Anderson and Y. Zeng (1998). Study of weak and strong motion including nonlinearity in the Northridge, California, earthquake sequence, Bull. Seism. Soc. Am. 88, 1411-1425.

Contacts

Please contact Dr. Feng Su (Phone: 775-784-6256, email: feng@seismo.unr.edu) for any available data from this research.

Figures and Figure Captions

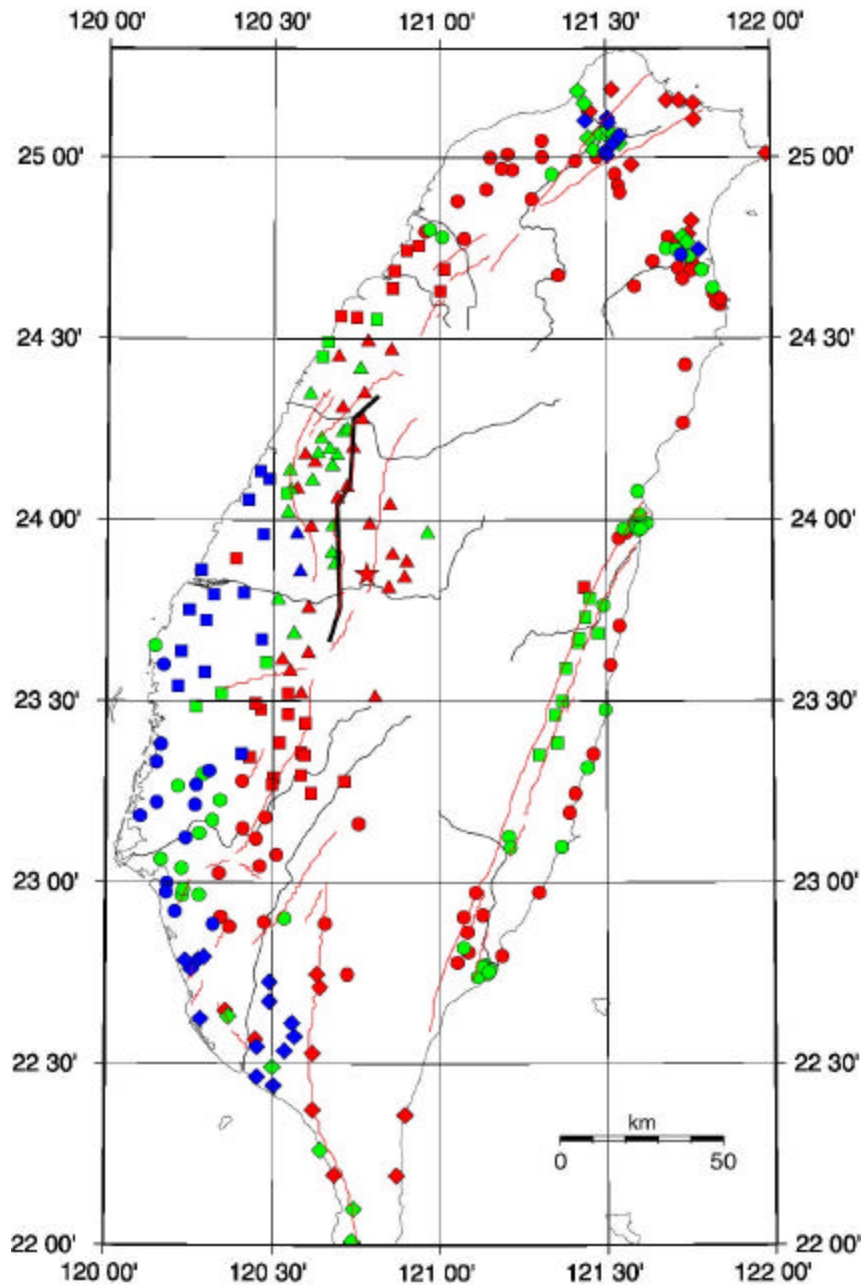Figure 1. Locations of strong motion accelerograph stations used in our study of the Chi-Chi earthquake. Symbol shape shows the distance range: Triangle: D<20km, Square: 20<D<50km; Solid circle: 50<D<100km; Diamond: D>100km. Shading indicating the site category: Red: hard sites; Green: medium sites; Blue: soft soil sites.
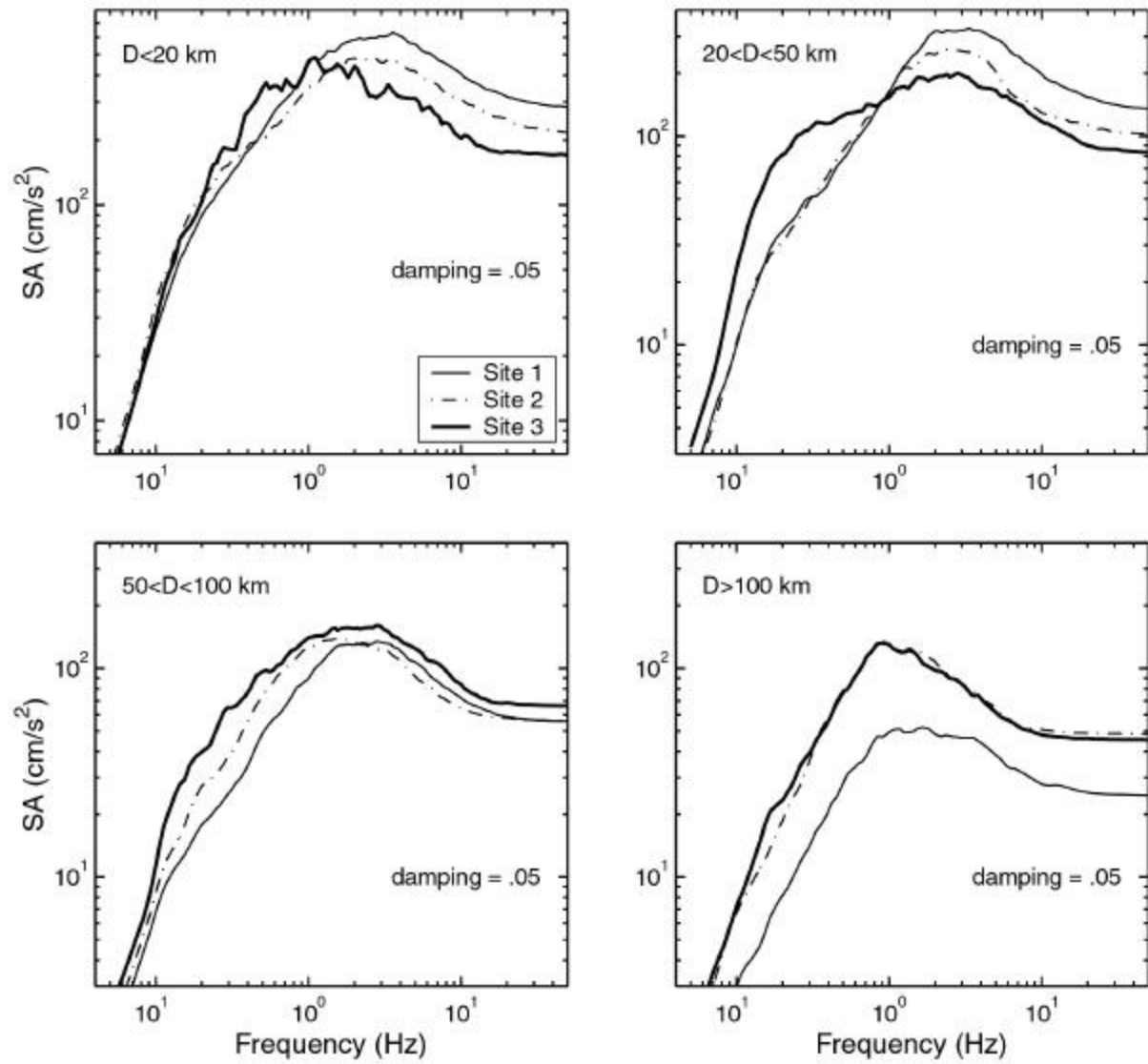
Figure 2: Compare average acceleration spectra of different site categories within the same distance range for Chi-Chi earthquake. (a) D<20km, (b) 20<D<50km; (c) 50<D<100km; (d) D>100km.
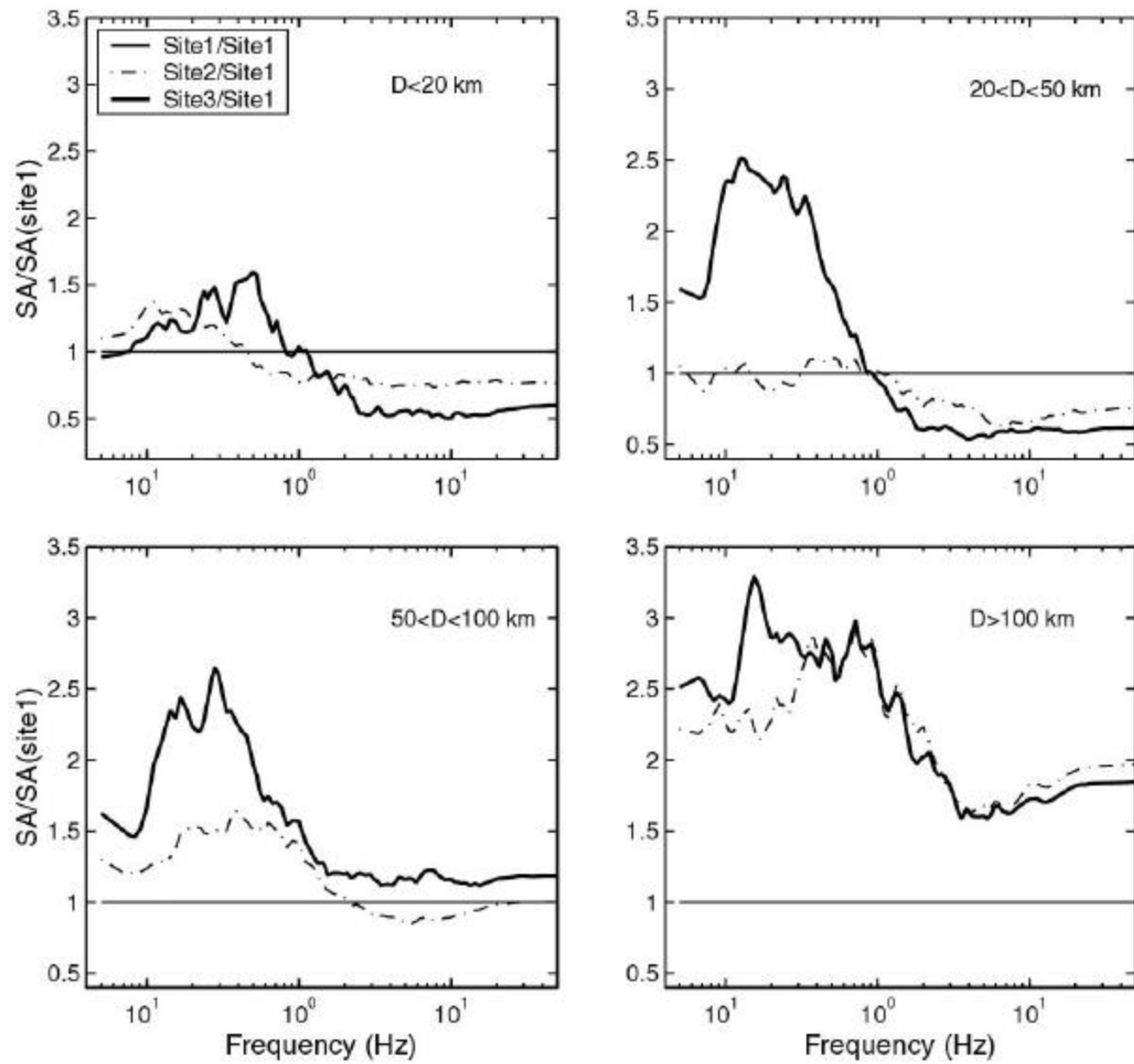
Figure 3. Ratios of response spectra with different site conditions determined from data from the Chi-Chi earthquake. The different frames show ratios for different distance ranges, as labeled in the figure.
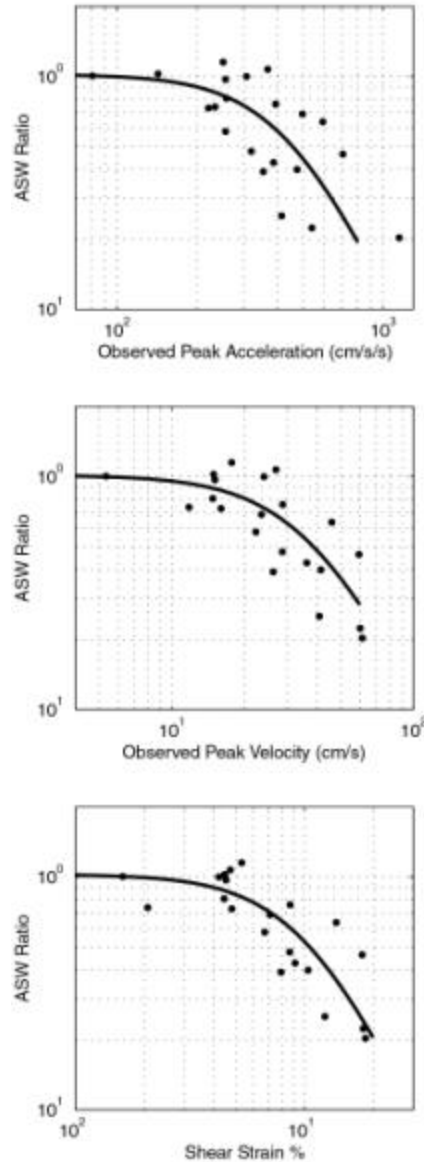
Figure 4. Re-plotted data from Figures 10-12 of Su et al (1998). Each point represents a separate station that recorded strong motion in the Northridge earthquake. Su et al determined the site response in the main shock and in smaller aftershocks, during which the soil was supposedly acting in a linear manner. The points give the average (over frequency) site amplification in the main shock to site amplification in the small events. The horizontal axis shows peak acceleration, peak velocity, or peak strain estimated from the main shock accelerogram. Deviations from unity are interpreted to be an indication of nonlinear site response in the main shock. Note that the threshold for nonlinearity in this earthquake was peak acceleration of about 0.3 g, peak velocity of about 20 cm/s, or peak strain of about 0.06%.
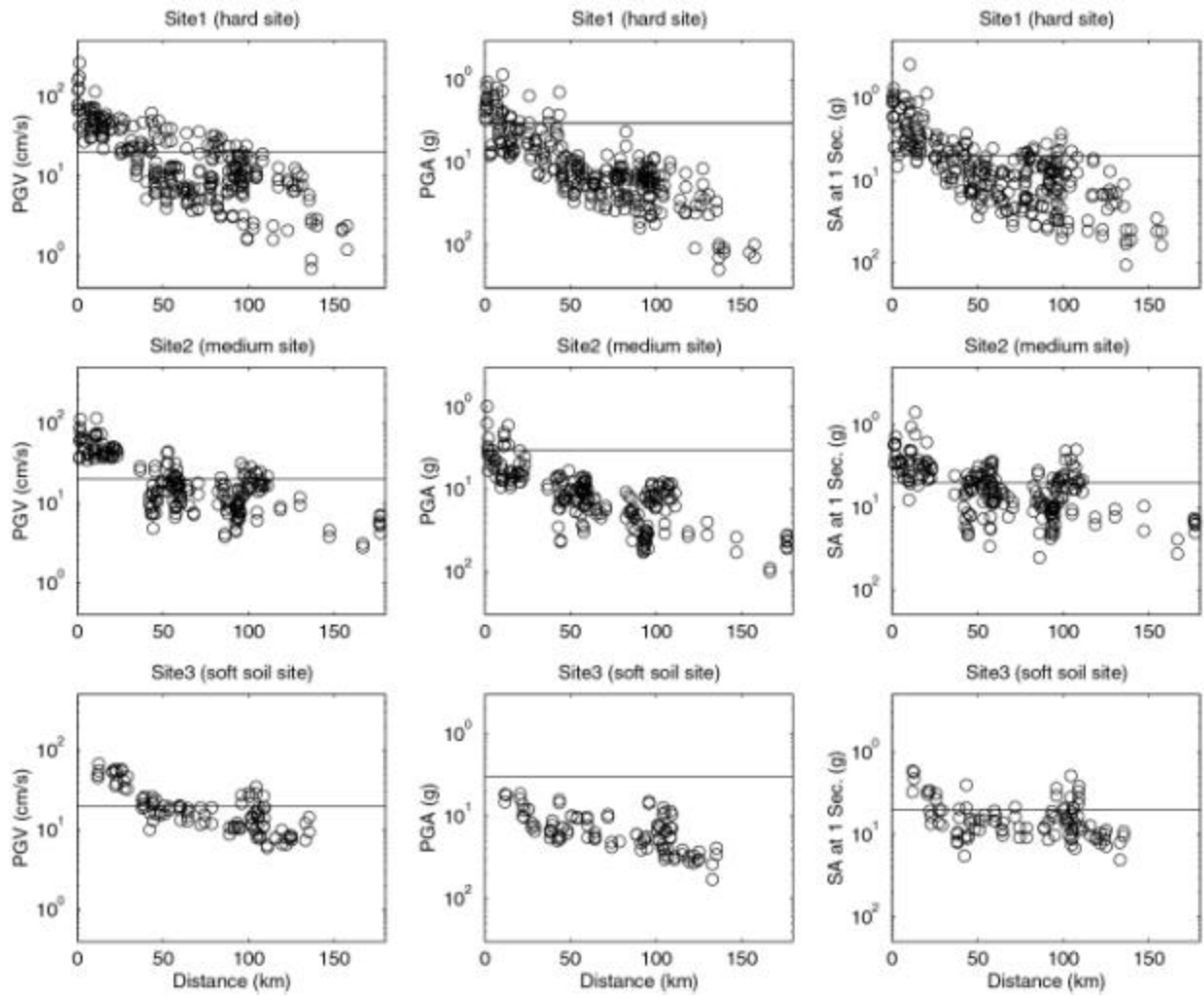
Figure 5. Peak acceleration and peak velocity in the Chi-Chi earthquake, as a function of distance. Different frames are for different site categories.
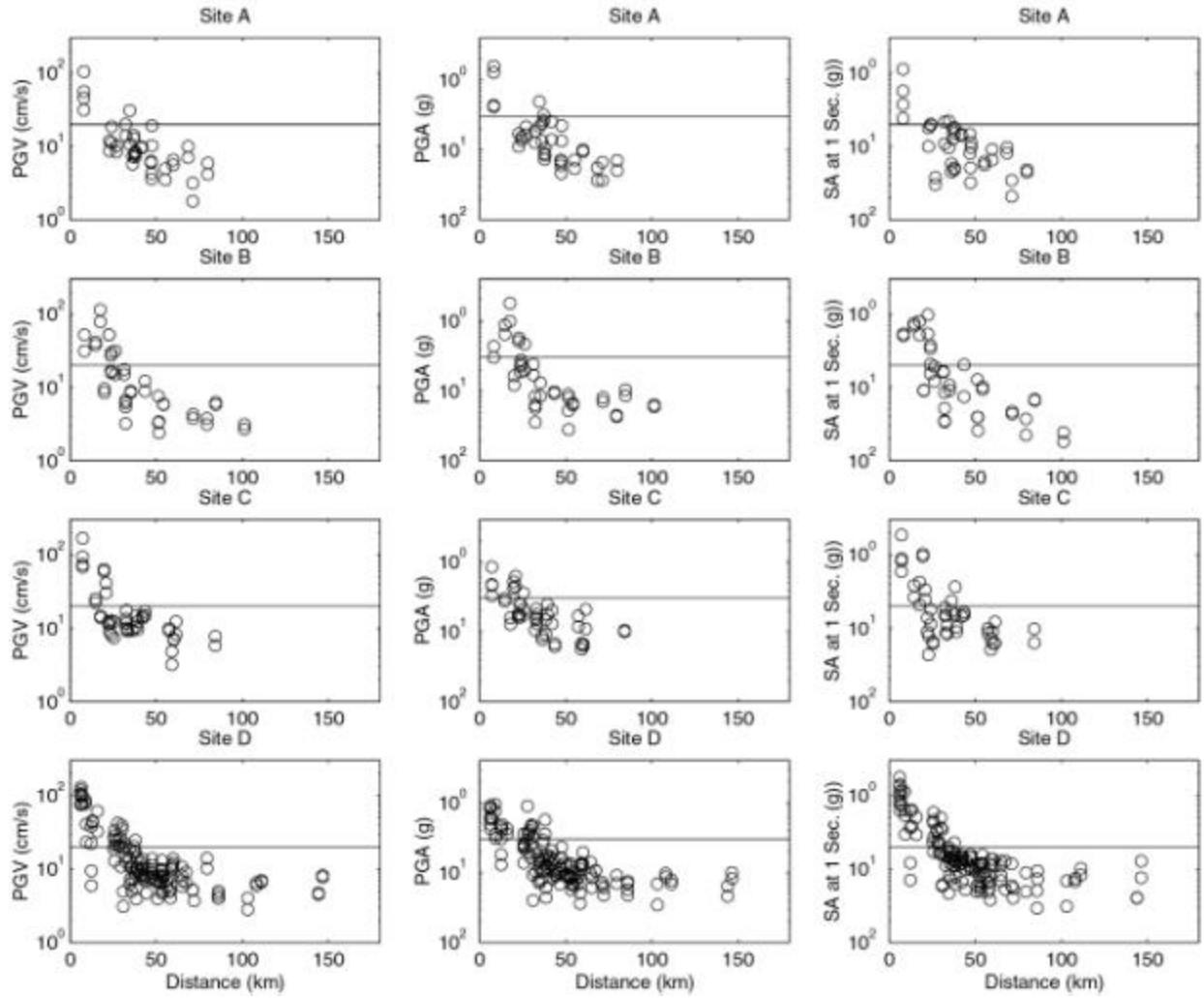
Figure 6. Peak acceleration and peak velocity in the Northridge earthquake, as a function of distance. Different frames are for different site categories.